Proceedings on Automation in Medical Engineering
Proc AUTOMED, Vol 2, No 1 (2023): Article Ref 772
www.journals.infinite-science.de/automed/article/view/772

Active field compensation using optically pumped magnetometers

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Abstract: Magnetoencephalography (MEG) using superconducting quantum interference devices is well established in neuroscience with a potential for clinical applications. New magnetic field sensors allow to fundamentally change MEG setups, and these will allow close to natural behavior of subjects and patients during measurements. Optically pumped magnetometers (OPM) can be operated close to the scalp and as single sensors allow almost free movements of participants. Their drawback is increased requirements for magnetic background field suppression in magnetically shielded rooms. Here a proof of principle setup is discussed to reduce field fluctuations in the mHz range.

I. Introduction

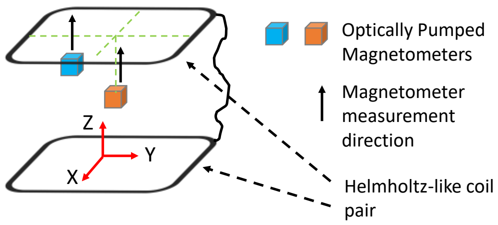
Imaging of neuronal activity of the brain can be done with electroencephalography (EEG) and magneto-encephalography (MEG). Despite the more complex equipment MEG has been in use for several decades since it yields complementary information to EEG [1]. New magnetic field sensors (e.g. [2]) open new possibilities for MEG and a range of developments are under way. A drawback of the currently most used SERF-optically pumped magnetometers (OPM) is their limited linearity range of ± 1 nT [2]. To use typical existing magnetically shielded rooms for OPM-MEG an additional active compensation is necessary [3-5] in the range below 1 Hz and down to 10 mHz. The approaches in [3] and [4] involve complicated coils inside the shielded room and the approach in [5] requires large coils on the outside of the room. Since the approach in [5] yields data of good quality [6] the present work explores a cost-effective internal coil system as a simplification of the outside coil approach.

II. Material and methods

An existing triple-axis Helmholtz-like coil system of dimension 45x45x45 cm was installed at the center of a two-layer magnetically shielded Ak3b room (www.vacuumschmelze.com). Inside the coil system two OPMs of the QZFM-type (www.quspin.com) were installed as shown in Fig. 1. One at the center (orange circle) and one 15 cm of the center in x- and z-direction (blue circle). The windings of the coil as copper lines on a printed circuit board can be seen at the bottom of the picture in Fig. 1 (b).

Then the off-center sensor measuring the z-direction of the magnetic field was connected to a PID controller (moku Go, www.liquidinstruments.com), whose output energized the z-coil of the coil system. Only the z-direction corresponding to the Earth normal was investigated since the field fluctuations are strongest in this direction in the urban environment in Berlin due to railway activity and other sources. The sensor at the center was used to quantify the degree of fluctuation damping of the control loop.

a)

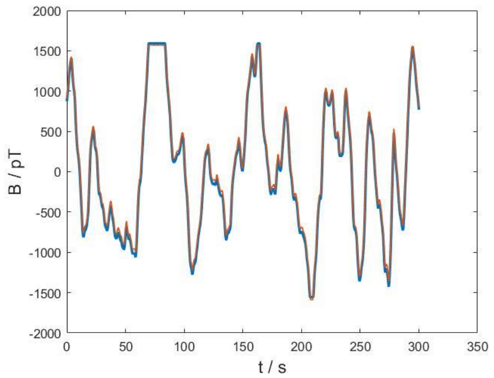


b)

Figure 1: (a) Sketch of the experimental setup. Two OPMs are placed between two parallel coils measuring the normal field generated by the coils (z-direction). The blue sensor gives the input signal for a PID controller driving the coils. The orange OPM at the center is used to assess the compensation effects. (b) Picture of the experimental setup. The copper lines of one coil are visible. This and the parallel coil at the bottom (white surface) are part of a Helmholtz-like cubic coil system. The sensors are marked by blue and orange circles and measure the z-direction of the field.

The settings of the PID controller were as follows: Proportional amplification was set at 1 dB and integrator saturation was at 20.6 dB. Integrator cut-off was at 3 Hz and use of differentiation was not necessary here for control.

a)



b)

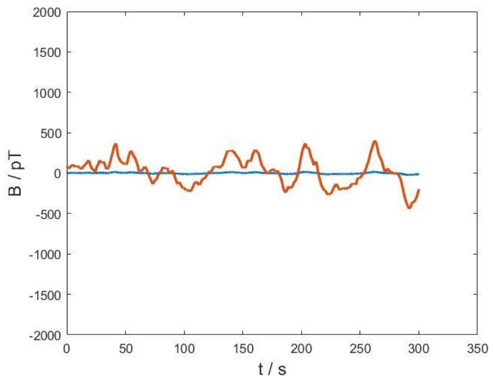


Figure 2: (a) OPM signals with PID control off. Both OPMs see the same background field fluctuations due to weak shielding of a two layer magnetically shielded room in the mHz range. At t=70 s saturation occurs. (b) PID control activated reduces the fluctuations below 500 pT even for the OPM at the center of the coil (orange trace). The OPM used as input for the PID shows a far superior reduction as expected (blue trace).

III. Results and discussion

The measured signals shown in Fig. 2 of the sensors at the off-center and at the center position were recorded with PID control off (a) and with PID control activated (b). With PID control off the fluctuations exceed the allowed range ± 1000 pT and even saturation occurs in the electronics of the sensor at t=70 s. Note, that the signals are almost identical in (a) for the two sensors since the orange curve is only faintly visible underneath the blue curve. The fluctuations in the room are due to outside field fluctuations only weakly attenuated by the mu-metal of the room at these frequencies. Consequently, the fluctuations are independent of location in the room. With PID control activated using the off-center signal in (b) even the center sensor signal is below ± 500 pT, which would allow to record MEG signals.

The compensation yields a rms field amplitude reduction by 40 dB at the off-center location of the sensor used as input for the PID (blue labeling in Figs. 1 and 2) and by 13 dB for the control sensor at the center of the coil (orange labeling in Figs. 1 and 2). Due to the inhomogeneous field distribution in this Helmholtz-like coil the off-center OPM cannot compensate fields in the center of the coil as good as at its own position.

The sensor used as input for the PID control (marked blue in Figs. 1 and 2) could be moved closer to the control sensor since they are of the same type and crosstalk occurs only below 2 cm separation [2]. Here we chose a larger distance since another type of sensor (e.g., fluxgate) might be used in an MEG application to simplify the setup of the active compensation and to lower the cost.

If the x- and y-directions are compensated additionally crosstalk between the directions needs to be considered and accounted for in a correction matrix. In our laboratory the z-fluctuations exceed the x- and y-fluctuations by a factor of three and sensors operate in the linear regime in the x- and y-direction [5].

IV. Conclusions

The proof of principle setup for a simple active compensation inside a magnetically shielded room shows sufficient suppression of mHz-field fluctuations to operate SERF-OPMs in the linear regime.

Scaling the geometric dimensions of the setup by a factor of four allows sufficient space for MEG measurements. Future work will investigate whether such a scaled setup achieves the same compensation efficiency.

Acknowledgments

THS thanks Allard Schnabel and Jens Voigt for helpful discussions.

Author's statement

Research funding: The authors state no funding involved. Conflict of interest: Authors state no conflict of interest.

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